National Aeronautics and Space Administration

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NTP CERMET Fuel Development Status

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Nuclear and Emerging Technologies for Space (NETS) 2017 Orlando, FL

MARSHALL SPACE FLIGHT CENTER

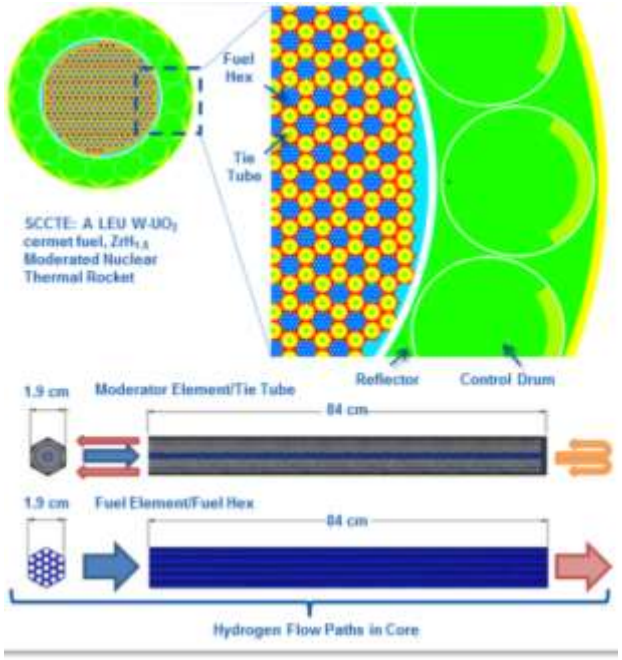
Presentation Overview

NTP CERMENT FUEL DEVELOPMENT

- GE710 Program
- NTP CERMET Fuel Development

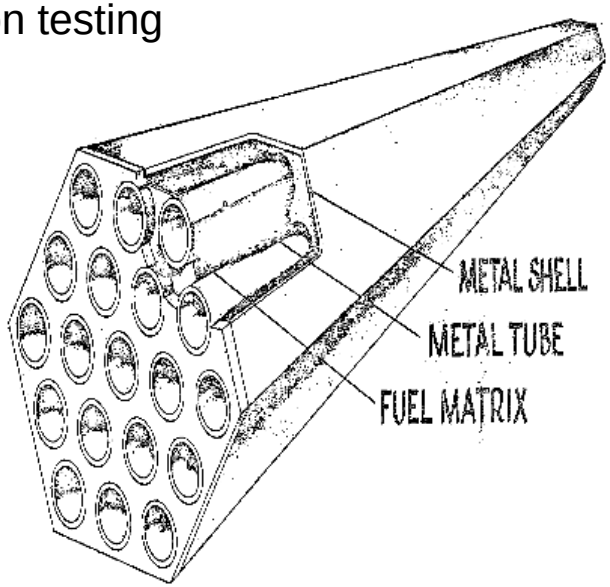
CERMET FABRICATION USING TUNGSTEN POWDER COATING AND SPARK PLASMA SINTERING

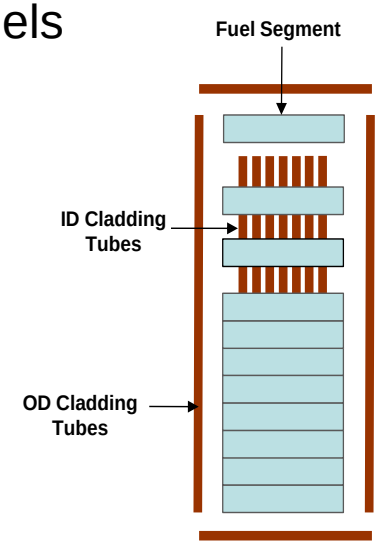
- Background
- Tungsten Powder Coating
- Spark Plasma Sintering
- Experimental Approach
- Results
- Conclusions



GE710 Program

- Extensive CERMET fuel development program
  - Over 15 million invested from May 1962 to Sept 1968
  - Operated fuel element fabrication line for reactor-sized fuel elements
  - Successfully fabricated 40+ W-60vol%UO_2 fuel elements for qual testing
    - Conducted over 300,000 hours of qualification testing
- 710 fabrication approach
  - Press and sinter W-UO_2 compacts
  - Machine cooling channels
  - Stack compacts
  - Weld tubes for cooling
  - Weld external cladding

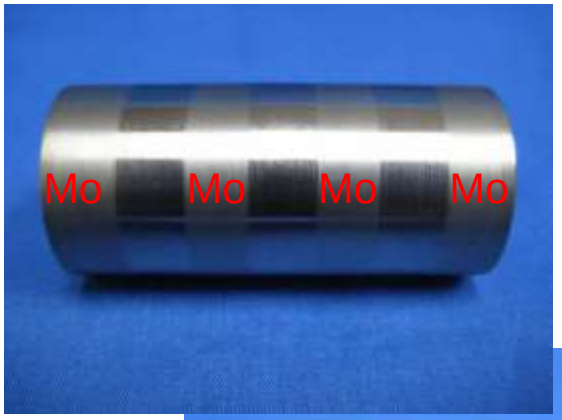


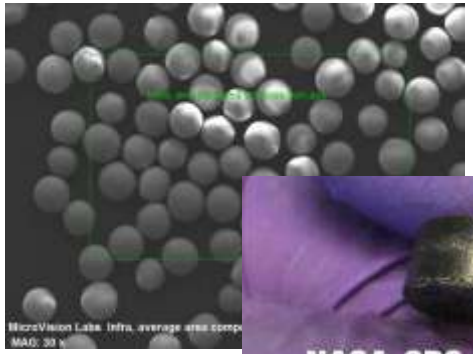


AEC Research and Development "*710 High Temperature Gas Reactor Program Summary Report*" GEMP-600; Vol I; 1969

NTP CERMET Fuel Development

- Hybrid GE710 Approach
  - GE710 approach with modern fabrication processes
    - Spark Plasma Sintering
    - Tungsten Powder Coating
- FY16 Development Efforts
  - Fabricated W-dUO_2 compacts using Spark Plasma Sintering and Tungsten Powder Coating
  - Phase I SBIR – Bonding tungsten CERMET compacts
  - Phase I SBIR - Electrolytic method for tungsten coating

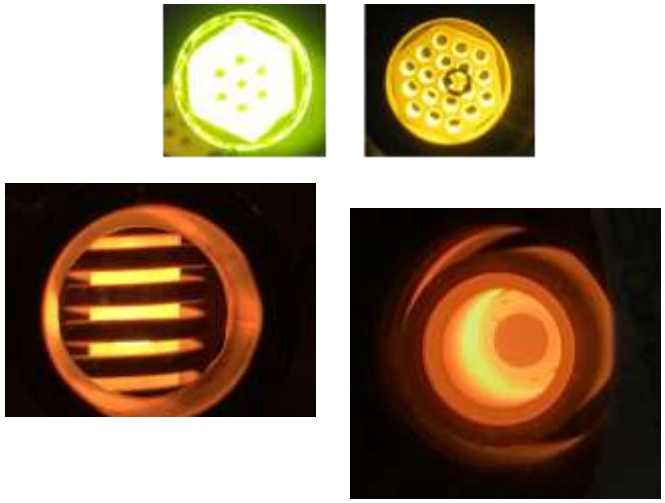




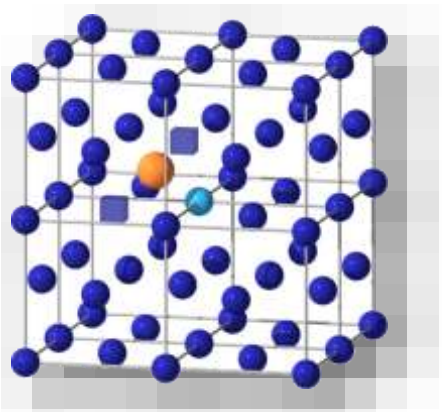
S. O'Dell "*Phase I Final Report Joining of Tungsten Cermet Nuclear Fuel",* Plasma Processes LLC, 2016

NTP CERMET Fuel Development

- FY17 Development Efforts
  - Developing process to fabricate subscale surrogate elements from compacts
  - Optimizing compact fuel element environmental testing (CFEET) apparatus
  - Initiating multiscale modeling task
  - Tungsten electron beam welding study
- FY18 Planning
  - SPS fabricate compacts with particles provided by BWXT
  - Hot hydrogen screening of W-dUO_2 compacts and subscale fuel segments



CFEET Testing



Multiscale Modeling

CERMET Fabrication using Tungsten Powder Coating and Spark Plasma Sintering

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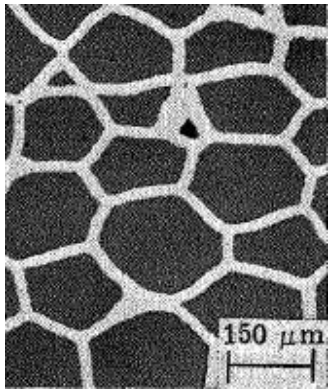
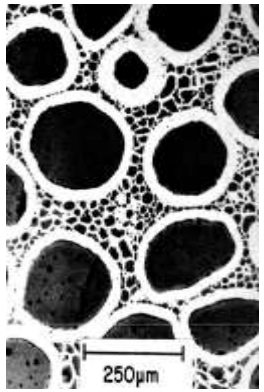
Background

- Past efforts focused on consolidating blended tungsten powder and uncoated dUO_2 particles
  - Poor quality feedstock
    - Large particle size distribution
    - Non-spherical particles - agglomeration
    - Need for coated particles
  - Particle segregation/non-uniform distribution of UO_2 within W matrix
  - Low density/ partial consolidation
  - Fuel element distortion
  - Explored CVD coating
    - Complex process due to the need to fluidize particles
- Developed W powder coating
  - Non compatible with past consolidation methods
  - Led to SPS
- Small amount of CIF funding augmented by NTP Project

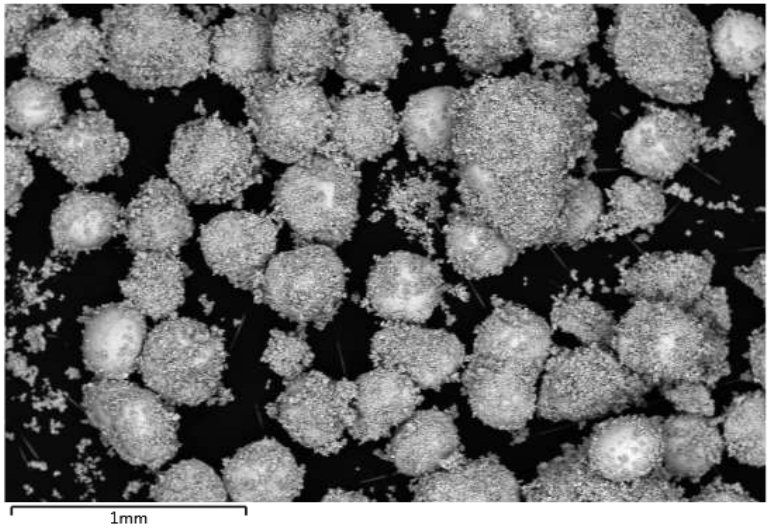


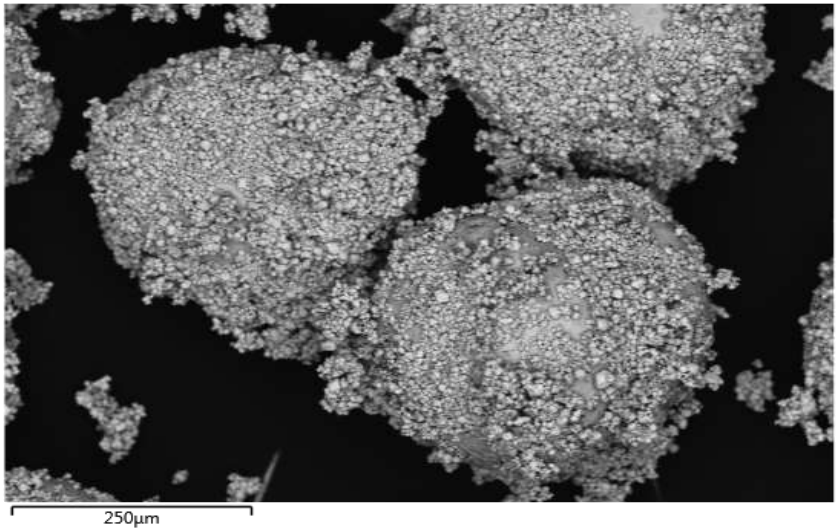


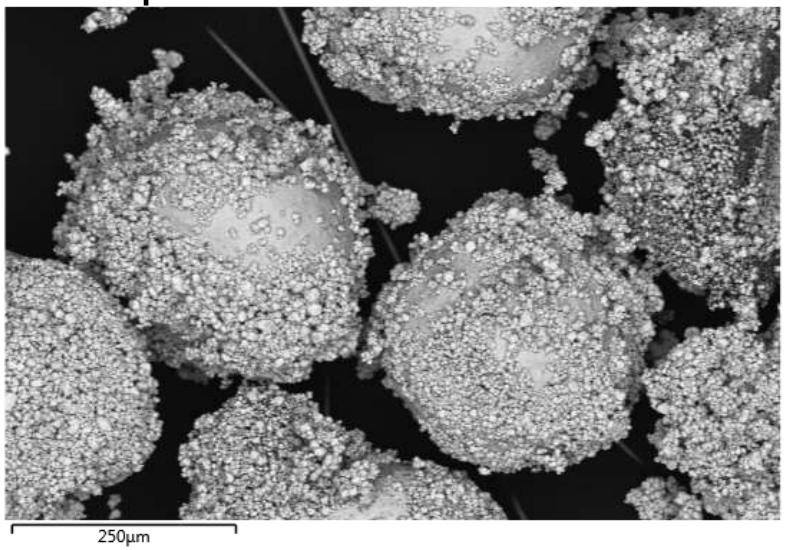
R.R. Hickman, *"Review of Past and Current W-UO2 CERMET Fuel Fabrication Development and Testing"*, National Aeronautics and Space Administration Marshall Space Flight Center, Huntsville, AL, 2014

Tungsten Powder Coating

- Straightforward approach to particle coating
- Conducted experiments with 6 different organic binders
- Coating Process
  - Blend W powder, dUO_2 particles, and binder
  - Stir mixture above binder drop point on hot plate for 5 min
- Not as uniformly coated as CVD coated particles



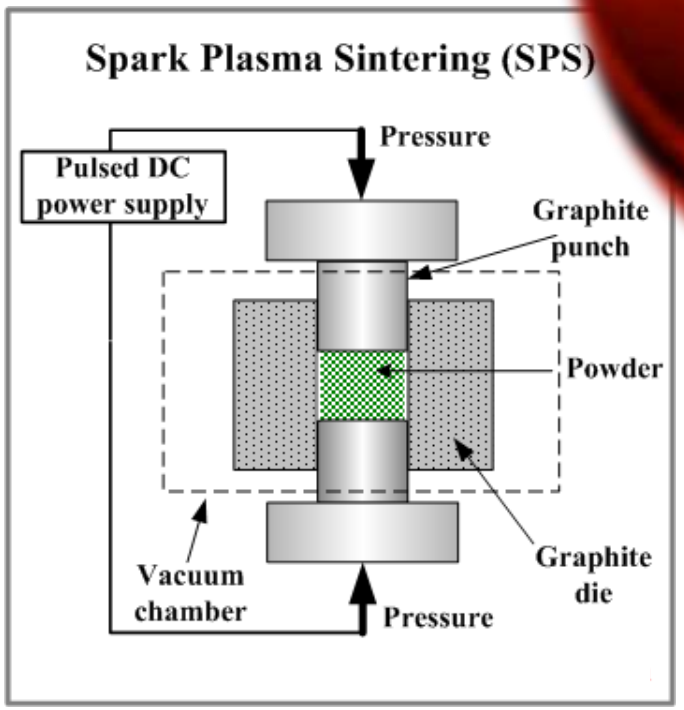


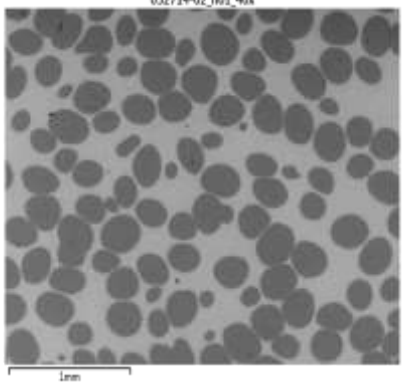


D. Tucker, A. O'Connor, R. Hickman., *"A Methodology for Producing Uniform Distribution of UO2 in a Tungsten Matrix"*, Journal of Physical Science and Application

Spark Plasma Sintering

- Rapid Consolidation/Sintering
- Net-shape/Near Net- Shape Parts
- High Density Parts
- Simple Process





1. Pictures courtesy of UC Davis and Substech
2. R.C. O'Brien, S.K. Cook, L.C. Hone. *"Fabrication of depleted UO2-W Cermet Fuel Elements via Spark plasma Sintering: Advances and Progress Made"*, Stennis Space Center, MS : s.n., 2014. Nuclear and Emerging Technologies (NETS).

Experimental Approach

- Utilized SPS system at CSNR to sinter W/UO_2 samples
  - Used W powder coated particles
- Sintered 24 samples at 1600C, 1700C, 1750C, 1800C, and 1850C peak temperatures
- 20-minute dwell time at peak temperatures; Pressure of 50 MPa
- Measured density and SEM
- TEM, hardness, and further SEM planned
- CFEET testing planned

Results

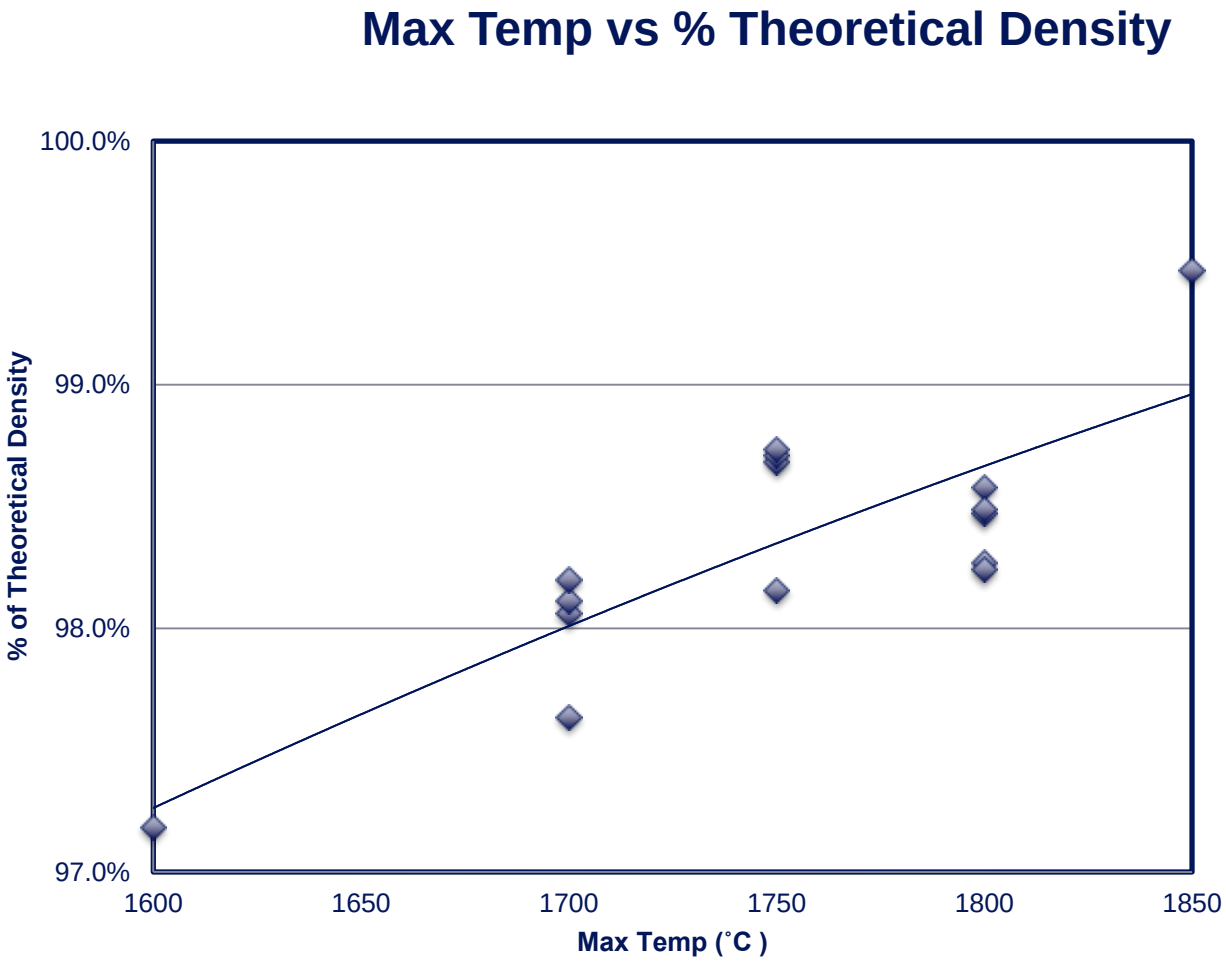
- Density
  - Increased with peak sintering temperature
  - Near theoretical density

Specimen	Thickness (mm)	Diameter (mm)	Average Density (g/cm^3)	Percent of Theoretical (%)
NASA-SPS-1850C-001	5.90	19.93	14.2	99.5
1800C-001	5.45	19.95	14.1	98.5
1800C-002	5.94	19.96	14.1	98.6
1800C-003	5.57	19.91	14.1	98.5
1800C-004	6.03	19.91	14.0	98.3
1800C-005	5.60	19.93	14.0	98.2
1750C-001	6.10	19.89	14.1	98.7
1750C-002	6.15	19.90	14.0	98.2
1750C-003	5.60	19.96	14.1	98.7
1750C-004	5.70	19.90	14.1	98.7
1700C-001	6.00	19.90	14.0	98.1
1700C-002	6.40	19.93	14.0	98.1
1700C-003	5.93	19.90	13.9	97.6
1700C-004	6.00	19.96	14.0	98.2
1600C-001	6.10	19.90	13.9	97.2

D. Tucker, M. Barnes, L. Hone, S Cook., *"High Density, Uniformly Distributed W/UO2 for use in Nuclear Thermal Propulsion"*, Journal of Nuclear Materials

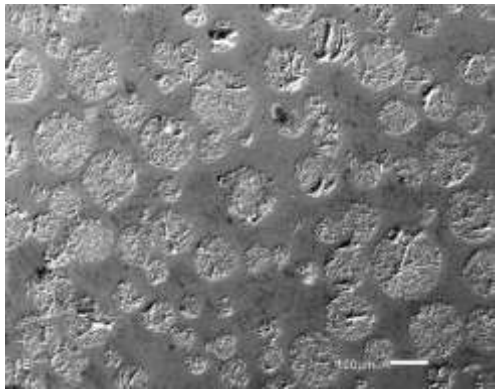
Results

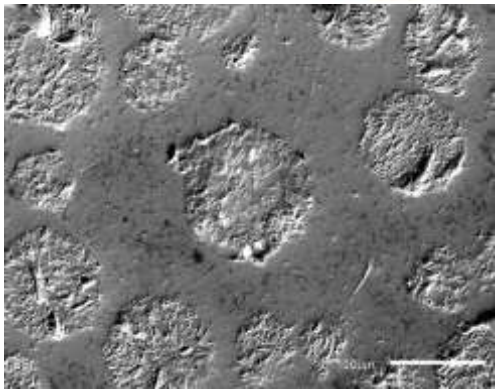
- Density

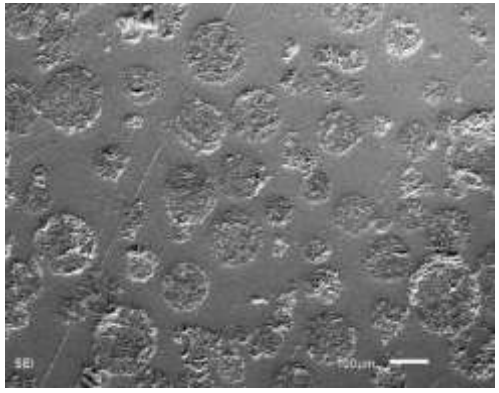


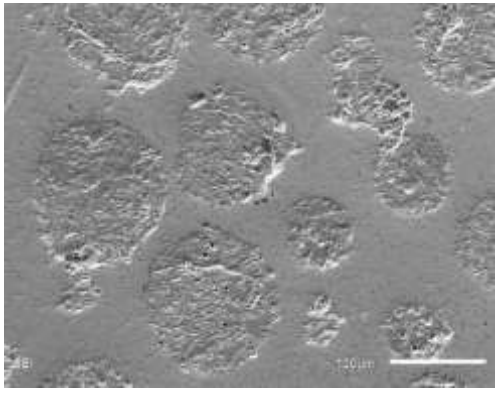
Results

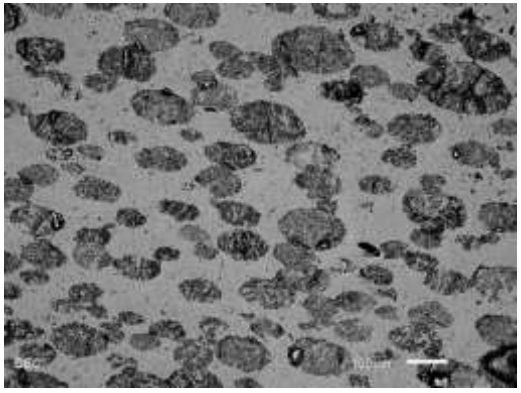
- SEM
  - Improved microstructure
  - UO_2 particles more uniformly dispersed
  - Cross-section depicts some particle elongation

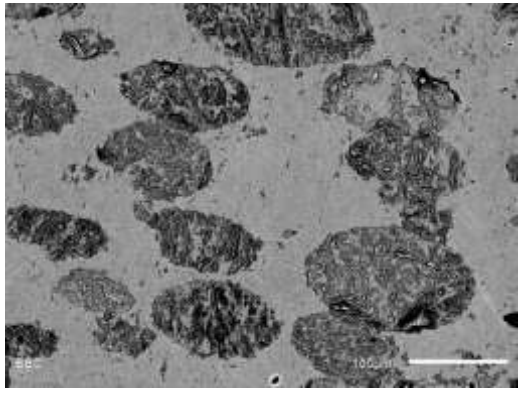








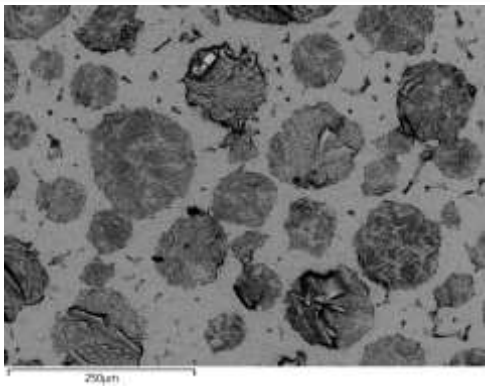


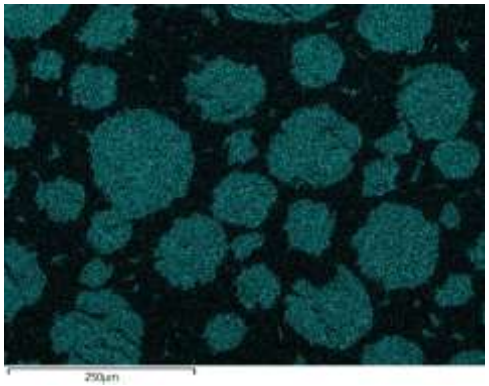


M. Barnes, D. Tucker, L. Hone, S Cook., *"Nuclear Rocket CERMET Fuel Fabrication using Tungsten Powder Coating and Spark Plasma Sintering"*, NASA Technical Paper

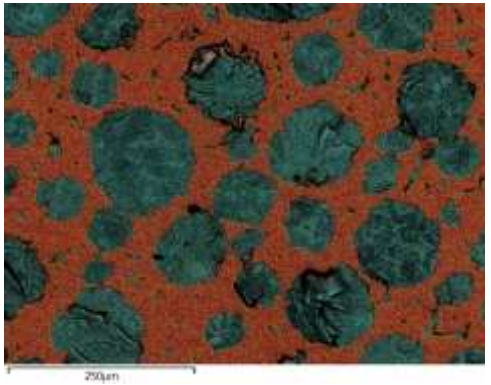
Results

- Energy-dispersive X-ray spectroscopy (EDS)
  - No unexpected phases

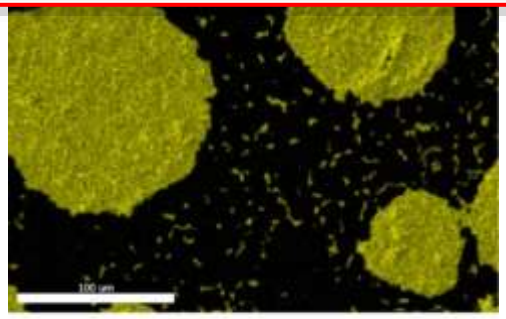




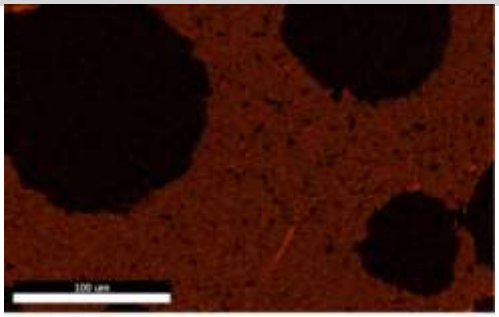
Uranium Phase



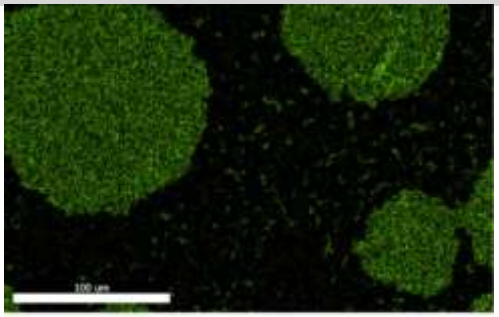
Tungsten Phase



Uranium Phase



Tungsten Phase



Oxygen Phase

Conclusions

- Improved mechanical properties and microstructure
- Further characterization needed and planned
  - Mechanical Properties
  - Thermal Properties
  - Chemistry
- Develop process to form elements from compacts
  - Stacking
  - Bonding
  - Cooling channel formation
  - Cladding